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Towards a musical programming language

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Abstract

This chapter introduces the concept of programming using music, also known as tone-based programming (TBP). There has been much work on using music and sound to debug code, and also as a way of help people with sight problems to use development environments. This chapter, however, focuses on the use of music to actually create program code, or the use of music as program code. The issues and concepts of TBP are introduced by describing the development of the programming language IMUSIC.

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Toward a Musical Programming Language

9

Alexis Kirke

Abstract

This chapter introduces the concept of programming using music, also known as tone-based programming (TBP). There has been much work on using music and sound to debug code, and also as a way of help people with sight problems to use development environments. This chapter, however, focuses on the use of music to actually create program code, or the use of music as program code. The issues and concepts of TBP are introduced by describing the development of the programming language IMUSIC.

9.1 Introduction

The motivations for programming using music are at least fivefold: to provide a new way for teaching script programming for children, to provide a familiar paradigm for teaching script programming for composition to non-technically literate musicians wishing to learn about computers, to provide a tool which can be used by sight-challenged adults or children to program (Sánchez and Aguayo 2006), to generate a proof of concept for a hands-free programming language utilizing the parallels between musical and programming structure, and to demonstrate the idea of increasing flow through real-time rhythmic interaction with a computer language environment.

AQ1

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9.1.1 Related Work

There have been musical languages constructed before for use in general (i.e., non-programming) communication—for example, Solresol (Gajewski 1902). There are also a number of whistled languages in use including Silbo in the Canary Islands. There are additionally whistle languages in the Pyrenees in France, and in Oacaca in Mexico (Busnel and Classe 1976; Meyer 2005). A rich history exists of computer languages designed for teaching children the basics of programming exists. LOGO (Harvey 1998) was an early example, which provided a simple way for children to visualize their program outputs through patterns drawn on screen or by a "turtle" robot with a pen drawing on paper. Some teachers have found it advantageous to use music functions in LOGO rather than graphical functions (Guzdial 1991).

A language for writing music and teaching inspired by LOGO actually exists called LogoRhythms (Hechmer et al. 2006). However, the language is input as text. Although tools such as MAX/MSP already provide non-programmers with the ability to build musical algorithms, their graphical approach lacks certain features that an imperative text-based language such as Java or MATLAB provide.

As well as providing accessibility across age and skill levels, sound has been used in the past to give accessibility to those with visual impairment. Emacspeak (Raman 1996), for example, makes use of different voices/pitches to indicate different parts of syntax (keywords, comments, identifiers, etc.). There are more advanced systems which sonify the development environment for blind users (Stefik et al. 2009) and those which use music to highlight errors in code for blind and sighted users (Vickers and Alty 2003). Audio programming language (APL) (Sánchez and Aguayo 2006) is a language designed from the ground up as being audio-based, but is not music-based.

By designing languages as tone-based programming languages from the ground up, they can also provide a new paradigm for programming based on "flow" (Csikszentmihalyi 1997). Flow in computer programming has long been known to be a key increaser of productivity. Also many developers listen to music while programming. This has been shown to increase productivity (Lesiuk 2005). It is also commonly known that music encourages and eases motion when it is synchronized to its rhythms. The development environment introduced here incorporates a real-time generative soundtrack based on programming code detected from the user and could support the user in coding rhythm and programmer flow through turning programming into a form of "jamming."

In relation to this, there has also been a programming language proposed called MIMED (Musically backed Input Movements for Expressive Development) (Kirke et al. 2014). In MIMED, it is proposed that the programmer uses gestures to code, and as the program code is entered, the computer performs music in real time to highlight the structure of the program. MIMED data is video data, and the language would be used as a tool for teaching programming for children, and as a form of programmable video editing. It can be considered as another prototype (though only in proposal form) for a more immersive form of programming that utilizes body

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rhythm and flow to create a different subjective experience of coding; the coder "dances" to the music to create program code.

9.2 Initial Conceptualization

The tone-based programming language which will be described later in this chapter is IMUSIC. It came about as a result of three stages of development which will now be described as they will give insight into the motivation and issues.

The initial motivations considered for the proposal of the first musical programming language were: It would be less language dependent; would allow a more natural method of programming for affective computing; would provide a natural sonification of the program for debugging; includes the possibility of hands-free programming by whistling or humming; may help those with accessibility issues; and would help to mitigate one element that has consistently divided the computer music community—those who can program and those who cannot.

The research in tools for utilizing music to debug programs (Vickers and Alty 2003; Boccuzzo and Gall 2009) and developer environments for non-sighted programmers (Stefik 2008) are based on the concept of sonification (Cohen 1994), i.e., turning non-musical data into musical data to aid its manipulation or understanding. One view of musical programming is that it is the reverse of this process, the use of music to generate non-musical data and processes, or desonification.

Musical structure has certain elements in common with program structure—this is one reason it has been used to sonify to help programmers debug. Music and programs are made up of modules and submodules. A program is made up of code lines, which build up into indented sections of code, which build up into modules. These modules are called by other modules and so forth, up to the top level of program. The top or middle level of the program will often utilize modules multiple times, but with slight variations. Most music is made up of multiple sections, each of which contain certain themes, some of which are repeated. The themes are made up of phrases which are sometimes used repeatedly, but with slight variations. (Also just as programmers reuse modules, so musicians reuse and "quote" phrases.) As well as having similarities to program structure, music contains another form of less explicit structure—an emotional structure. Music has often been described as a language of emotions (Cooke 1959). It has been shown that affective states (emotions) play a vital role in human cognitive processing and expression (Malatesa et al. 2009). As a result, affective state processing has been incorporated into artificial intelligence processing and robotics (Banik et al. 2008). This link between music and artificial intelligence suggests that the issue of writing programs with affective intelligence may be productively addressed using desonification.

Software desonification is related to the field of natural programming (Myers and Ko 2005)—the search for more natural end user software engineering. There is also a relationship between software desonification software and constraint-based, model-based, and automated programming techniques. A musical approach to

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programming would certainly be more natural to non-technically trained composers/performers who want to use computers, but it may also help to make computer programming more accessible to those who are normally nervous of interacting with software development environments. The use of humming or whistling methods may help to open up programming to many more people. If such an approach seems unnatural, imagine what the first QWERTY keyboard must have seemed like to most people. What would once have seemed like an unnatural approach is now fully absorbed into our society.

9.2.1 Structure-Based Desonification for Programming

The development of a generalized theoretical approach is beyond the scope of this chapter. Hence, we will use the approach of giving examples to explicate some key issues. Musical structure is often described using a letter notation. For example, if a piece of music has a section, then a different section, then a repeat of the first section, it can be written as ABA. If the piece of music consists of the section A, followed by B and then a variation on A, it can be written as ABA′ ("A", "B", "A prime"). Another variation on A could be written as A″. Some forms in music are as follows:

- Strophic—AAAA…;
- Medley—e.g., ABCD…, AABBCCDD…, ABCD…A′, AA′A″A‴A⁗;
- Binary—e.g., AB, AABB…;
- Ternary—e.g., ABA, AABA;
- Rondo—e.g., ABACADAEA, ABACABA, AA′BA″CA‴BA⁗, ABA′CA′B′A; and
- Arch—ABCBA.

There has been a significant amount of work into systems for automated analysis of music structure—e.g., (Paulus and Klapuri 2006)—though it is by no means a solved problem.

Suppose a piece of music has the very simple form in three sections ABA'. A is made up of a series of phrases and is followed by another set of phrases (some perhaps developing the motifs from the phrases in B), and A' is a transformed recapitulation of the phrases in A. Next suppose the sections A, B can be broken down into themes:

$$\mathrm{A} = [xy]$$
$$\mathrm{B} = [eff]$$

So i is a theme x, followed by a theme y. And B is a theme e followed by the theme f repeated twice. How might this represent a program structure? The first stage of a possible translation is shown in Fig. 9.1.

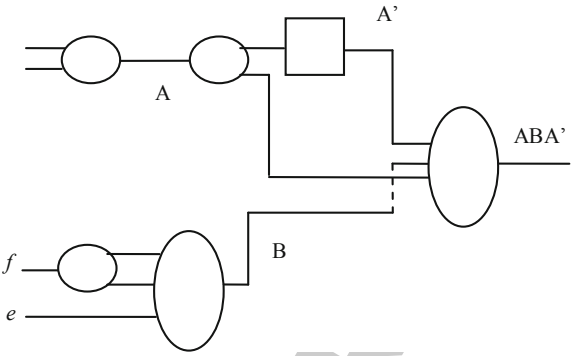

Fig. 9.1 Graphical representation of structure

Each shape is an operation—the elliptical shapes represent ordered combinations (as in A is a combination of x and y in that order) or decombinations (as in B includes two fs). Squares are transformations of some sort. Many mappings are possible, for example, suppose that the combiners represent addition, the decombiners division by two, and the transformation is the sine function. Then, the piece of music would represent a program:

$$\text{Output} = \sin((x + y)/2) + (x + y)/2 + f/2 + f/2 + e$$

However, such a specific mapping is of limited general utility. Removing such specific mappings, and returning to the abstraction based on the structure in Fig. 9.1, and turning it into pseudocode could give something like Fig. 9.2.

The simplest way to explicate how this program relates to the musical structure is to redraw Fig. 9.1 in terms of the code notation. This is done in Fig. 9.3. The multi-input ellipses are *functionP()*, the multi-output ellipses are *functionQ()*, and the square is *functionR()*.

A few observations to make about this generated code are that even at this level of abstraction it is not a unique mapping of the music of the graphical representation of the music in Fig. 9.1. Furthermore, it does not actually detail any algorithms—it is structure-based, with "to-dos" where the algorithm details are to be inserted. The question of how the to-dos could be filled in is actually partially implicit in the diagrams shown so far. The translation from A to A' would usually be done in a way which is recognizable to human ears. And if it is recognizable to human ears, it can often be described verbally, which in turn may be mappable to computer code of one sort or another. For example, suppose that the change is a raising or lowering of pitch by 4 semitones, or doubling the tempo of the motifs, or any of the well-known transformations from Serialist music. Mappings could be defined from these transformations onto computer code, for example, pitch rise could be addition, tempo change multiplication, and in the case of matrices (e.g., in MATLAB programming), the mapping matrix from A to A′ could be calculated using inverse techniques.

The transformation ideas highlight the approach of utilizing only the graphical form of the program mapping; i.e., programming using the MAX/MSP or Simulink

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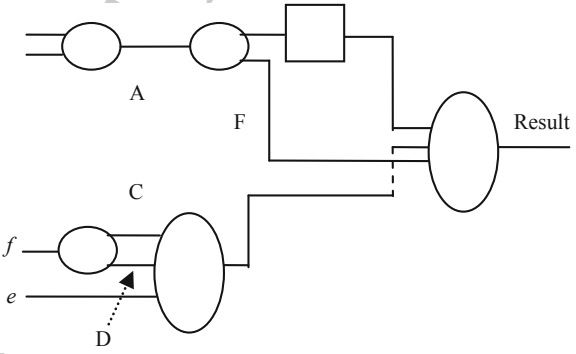
Fig. 9.2 Pseudocode representation of ABA' piece

```
Def functionP(v1,v2,v3)
        //todo
End
Def functionQ(v1)
        //todo
End
Def functionR(v1, v2)
        //todo
End
        //
Def result = Main(x,y,e,f)
    Def A as var;
    Def B as var;
    Def Ap as var;
    A = functionP(x,y);
    [C,D] = functionQ(f);
    B = functionP(e,C,D);
    [E,F] = functionQ(A);
    Ap = functionR(E);
    Result= functionP(Ap,B,F);
end
```

Fig. 9.3 Fig. 9.1 adjusted to explicate code in Fig. 9.2



approach. These methods are sometimes used by people who have limited software programming knowledge. So rather than converting the musical performance into textual code, such users may prefer to work with the graphical mappings. Such graphical mappings may suggest different emphases in approach to those found in mappings to text code in Fig. 9.3. In the MAX-type case, the role of motifs as "place-holders" is emphasized and the transformations performed on the motifs become the key constructive elements. Also the graphical methods provide a possible real-time approach to programming. It would be easier for a user to see a steadily building graphical program while they play than to see the textual code. As can be seen from the above, part of the problem with investigating desonification

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for software is the number of possible mappings which could be defined. And given that a desonification approach to programming is so novel, testing different mappings is a complex process. Users would first need to become comfortable with the concept of programming by music, and then, we could compare different mapping techniques. But for them to become comfortable with the techniques, the techniques should have been defined in the first place. Finding a likely set of techniques to test is a key problem for future work.

9.2.2 Initial Implementation Ideas

How to implement musical programming is an open issue. Discussing the CAITLIN musical debugging system, (Vickers and Alty 2003) describes how "Ultimately, we hope the sound and light displays of multimodal programming systems will be standard items in the programmer's toolbox" and that "that combining auditory and visual external representations of programs will lead to new and improved ways of understanding and manipulating code." Another audio-based system—WAD—has actually been integrated into MS Visual Studio (Stefik 2008). One way of implementing desonification for programming would be in a musically interactive environment. The user would see the program and hear a sonification of the program behavior or structure; they would then be able to play along on a MIDI keyboard or hum/whistle into a microphone to adjust the structure/behavior. One issue with this is that sonification for audible display of program structure is a different problem. The types of musical mappings which best communicate a program structure to a user may not be the best types of musical mappings which allow a user to manipulate the structure. A compromise would need to be investigated.

In the case of textual programming languages, it may be necessary to actually sonify the structure as the user develops it—then, the programming process would be that of the user "jamming" with the sonification to finalize the structure. For desonification for graphical programming, it may be simplest to just display the graphical modular structure and mappings generated by the music in real time as the music is being performed by the user and analyzed by the desonifier. One obvious point with any environment like this is it would require some practice and training. The issues of these environments are obviously key to the utility of software desonification, and attempts have been made to address some of these issues later in the chapter.

9.2.3 Other Possible Desonification Elements for Programming

Another feature which music encodes is emotion. There has been some work on systems (Kirke and Miranda 2015; Friberg 2004) that take as input a piece of music and estimate the emotion communicated by the music—e.g., is it happy, sad, angry,

etc. Affective state processing has been incorporated into artificial intelligence processing and robotics. It may be that the issue of writing programs with affective intelligence can be productively addressed using software desonification. Emotions in artificial intelligence programming are often seen as a form of underlying motivational subsystem (Izumi et al. 2009). So one approach to software desonification would be to generate the program structure using similar ideas already discussed in the structure section earlier and then to generate a motivational subsystem through the emotional content of the music. Obviously, this would require a different type of awareness in the musician/programmer, and it is not clear how any "if…then"-type structure could emerge from the emotive layer only. One way might be as follows. There has been research which demonstrates that music can be viewed dramatically, with "characters" emerging and interacting (Maus 1988). This could provide a structure for which to map onto a multi-agent-based programming environment, where agents have an affective/motivational substructure.

Musical programming could potentially be used in helping to create more believable software for affective computing, for example, chat agents. Well-written music is good at communicating emotions and communicating them in an order that seem natural, attractive, or logical. This logic of emotion ordering could be used to program. Suppose a software programming environment utilizes one of the algorithms for detecting emotion in music. If a number of well-known pieces of music are fed into the programming environment, then in each piece of music it would auto-detect the emotional evolution. These evolutions could be transferred as, for example, Markov models into an agent. Then, the agent could move between emotional states when communicating with users, based on the probability distribution of emotional evolution in human-written music. So the music is being used as emotional prototypes to program the agent's affective layer. One aspect of musical performance which linear code text cannot emulate is the ability for multiple performers to play at the same time and produce coherent and structured music. Whether this has any application in collaborative program could be investigated.

9.3 Music

After the initial conceptualization, an example language was constructed and proposed called MUSIC (Music-Utilizing Symbolic Input Code). Although MUSIC was never implemented, its conception is instructive as it highlights constraints and possibilities of musical programming. It also is instructive in its contrast with the implemented version of MUSIC called IMUSIC, discussed later.

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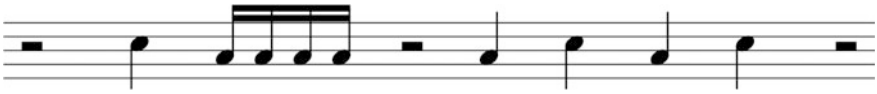

Fig. 9.4 Examples of input types

9.3.1 MUSIC Input

A MUSIC input string can be an audio file or a MIDI file, consisting of a series of sounds. If it is an audio file, then simple event and pitch detection algorithms (Lartillot and Toiviainen 2007) are used to detect the commands. The command sounds are made up of two types of sound: dots and dashes. A dot is any sound less than 300 ms in length, a dash is anything longer. Alternatively, a dot is anything less than 1/9 of the longest item in the input stream.

A set of input sounds is defined as a "grouping" if the gaps between the sounds are less than 2 s and it is surrounded by silences of 2 s or more. Note that these time lengths can be changed by changing the Input Tempo of MUSIC. A higher input tempo setting will reduce the lengths described above. Figure 9.4 shows two note groupings. The first is made up of a dash and 4 dots, the second grouping is made up of 4 dashes (note—all common music notation is in the treble clef in the chapter).

9.3.2 Commands

Table 9.1 shows some basic commands in MUSIC. Each command is a note grouping made up of dots and/or dashes; hence, it is surrounded by a rest. Column 2 gives what is called the Symbol notation. In Symbol notation, a dot is written as a period "." and a dash as a hyphen "-". Note grouping gaps are marked by a forward slash "/". The symbol notation is used here to give more insight into those who are unfamiliar with musical notation. AQ4

Although MUSIC's commands can be entered ignoring pitch there are pitched versions of the commands which can be useful either to reduce the ambiguity of the sonic detection algorithms in MUSIC or to increase structural transparency for the user. The basic protocol is that a "start something" command contains upward movement or more high pitches, and a "stop something" command contains lower pitches and more downward pitch movement. This can create a cadence-like or "completion" effect.

For example, Print could be 4th interval above the End Print pitch. A Repeat command could be two pitches going up by a tone, and End Repeat the same two notes but in reverse pitch order. The rhythm definitions all stay the same and rhythm features are given priority in the sound recognition algorithms on the input in any case. However, using the pitched version of MUSIC is a little like indenting structures in C++ or using comments, it is a good practice as it clarifies structure. In AQ5

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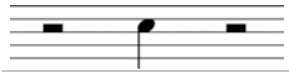
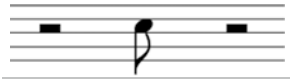
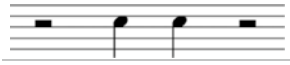
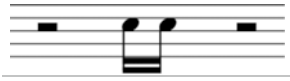
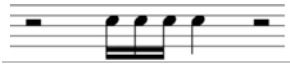
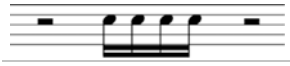
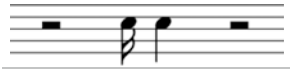
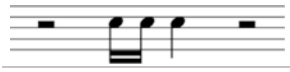
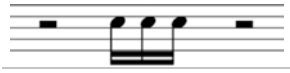
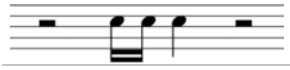
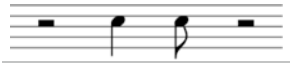
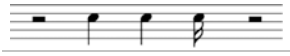
Table 9.1 Core music commands

Input grouping	Symbols	Name
	/-/	Print
	/./	End Print
	/–/	Repeat
	/../	End Repeat
	/….-/	Define Object
	/…./	End Object
	/.-/	Use Object
	/..-/	Operator
	/…/	End Operator
	/..–/	Linear Operator
	/-./	Input
	/–./	If Silent

fact, it would be possible to change the MUSIC input interface to force a user to enter the pitched version should they wish. In addition, it turns a music program into an actual tune, rather than a series of tunes bounded by Morse code-type sounds. This tune-like nature of the program can help the user in debugging (as will be explained later) and to perhaps understand the language from a more musical point of view.

There is also an input mode called Reverse Rhythm, in which the start and stop command rhythms are reversed. In the default input mode shown in Table 9.1, a command starts with a longer note (a dash) and ends with a shorter note (a dot). However, it is quite common in musical cadences to end on a longer note. So if a user prefers, they can reverse the rhythms in the stop and start commands in Table 9.1 by switching to Reverse Rhythm mode.

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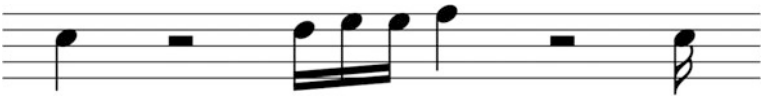

Fig. 9.5 A print example

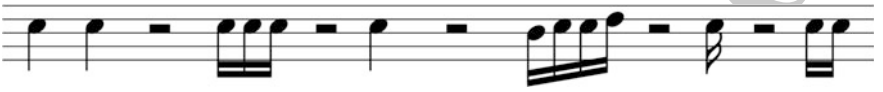

Fig. 9.6 A repeat example

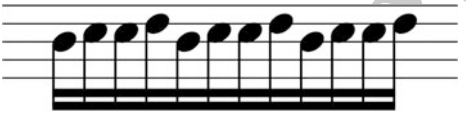

Fig. 9.7 MUSIC output from Fig. 9.6 repeat

9.3.3 Examples

The Print command in Table 9.1 will simply treat the sounds between itself and the Stop Print command as actual musical notes, and simply output them. It is the closest MUSIC has to the PRINT command of BASIC. For example, suppose a user approximately whistles, hums, and/or clicks, the tune is shown in Fig. 9.5 (Symbols "/-/BCCD/./"). Then, MUSIC will play back the 4 notes in the middle of the figure (B, C, C, D) at the rhythm they were whistled or hummed in.

The Repeat command in Table 9.1 needs to be followed in a program by a note grouping which contains the number of notes (dots or dashes) equal to the number of repeats required. Then, any operation between those notes and the End Repeat note grouping will be repeated that number of times. There are standard repeat signs in standard musical notation, but these are not very flexible and usually allow for only one. As an example of the Repeat command, Fig. 9.6 starts with a group of 2 dashes, indicating a Repeat command (Symbols: "/–/…/-/BCCD/./../") and then a group of 3 dots—indicating repeat 3 times. The command that is repeated 3 times is a Print command which plays the 4 notes in the 4th note grouping in Fig. 9.6 (B, C, C, D). So the output will be that as shown in Fig. 9.7—the motif played three times (BCCDBCCDBCCD).

9.3.4 Objects

The previous example, in Figs. 9.6 and 9.7, shows a resulting output tune that is shorter than the tune which creates it—a rather inefficient form of programming!

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Functionality is increased by allowing the definition of Objects. Examples will now be given of an Outputting object and an Operating object. An outputting object will simply play the piece of music stored in it. An example of defining an outputting object is shown in Fig. 9.8. The Define and End Object commands can be seen at the start and end of Fig. 9.8's note streams, taken from Rows 5 and 6 of Table 9.1.

The motif in the second grouping of Fig. 9.8 (B, D, B) is the user-defined "tone name" of the object, which can be used to reference it later. The contents of the object is the 7 note motif in the 4th note grouping in Fig. 9.5 (B, C, C, D, C, D, B). It can be seen that this motif is surrounded by Print and End Print commands. This is what defines the object as an Outputting object. Figure 9.9 shows a piece of MUSIC code which references the object defined in Fig. 9.8. The output of the code in Fig. 9.9 will simply be to play the tune BCCDCDB twice, through the Use Object command from Table 9.1.

The next type of object—an operating object—has its contents bordered by the Operator and End Operator commands from Rows 8 and 9 in Table 9.1. Once an operator object has been defined, it can be called, taking a new tune as an input, and it operates on that tune. An example is shown in Fig. 9.10.

Figure 9.10 is the same as Fig. 9.6 except for the use of the Operator and End Operator commands from Table 9.1, replacing the Print and End Print commands in Fig. 9.8. The use of the Operator command turns the BCCDCDB motif into an operation rather than a tune. Each pitch of this tune is replaced by the intervals input to the operation. To see this in action, consider Fig. 9.11. The line starts with the Use Object command from Table 9.1, followed by the name of the object defined in Fig. 9.10. The 3rd note grouping in Fig. 9.11 is an input to the operation. It is simply the two notes C and B.

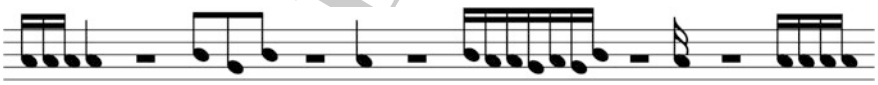

Fig. 9.8 An outputting object

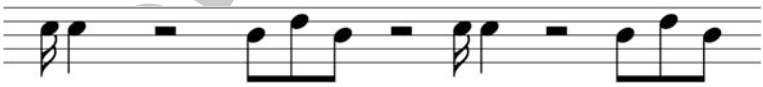

Fig. 9.9 Calling the object from Fig. 9.8 twice

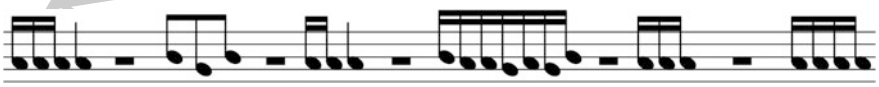

Fig. 9.10 Defining an operator object

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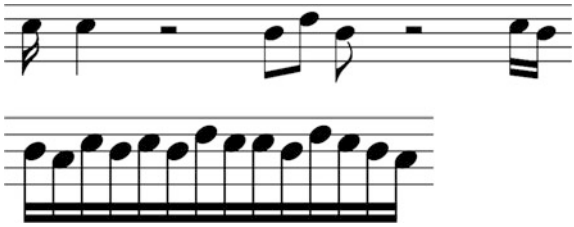

Fig. 9.11 Calling an operator object, and the resulting output

The resulting much longer output shown in the bottom line of Fig. 9.11 comes from MUSIC replacing every note in its operator definition with the notes C and B. So its operator was defined in Fig. 9.10 with the note set BCCDCDB. Replacing each of these notes with the input interval CB, we get BACBCBDCCBDCBA which is the figure in the bottom line of Fig. 9.11. Note that MUSIC pitch quantizes all data to C major by default (though this can be adjusted by the user).

9.3.5 Other Commands and Computation

It is beyond the scope of this description to list and give examples for all commands. However, a brief overview will be given of the three remaining commands from Table 9.1. The Linear Operation command in Table 9.1 actually allows a user to define an additive operation on a set of notes. It is a method of adding and subtracting notes from an input parameter to the defined operation. When an input command (in the last-but-one row of Table 9.1) is executed by MUSIC, the program waits for the user to whistle or input a note grouping and then assigns it to an object. Thus, a user can enter new tunes and transformations during program execution. Finally, the If Silent command in the last row of Table 9.1 takes as input an object. If and only if the object has no notes (known in MUSIC as the Silent Tune), then the next note grouping is executed.

Although MUSIC could be viewed as being a simple to learn script-based "composing" language, it is also capable of computation, even with only the basic commands introduced. For example, printing two tunes T1 and T2 in series will result in an output tune whose number of notes is equal to the number of notes in T1 plus the number of notes in T2. Also, consider an operator object of the type exemplified in Figs. 9.10 and 9.11 whose internal operating tune is T2. Then, calling that operator with tune T1 will output a tune of length T1 multiplied by T2. Given the Linear Operator command which allows the *removing* of notes from an input tune, and the If Silent command, there is the possibility of subtraction and division operations being feasible as well.

As an example of computation, consider the calculation of x^3 the cube of a number. This is achievable by defining operators as shown in Fig. 9.12. Figure 9.12 shows a usage of the function to allow a user to whistle x notes and have x^3 notes

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1 Input X
2 Define Object Y
3 Operator
4 Use Object X
5 End Operator
6 End Object
7 Print
8 Use Object(Y, Use Object(Y,X)))
9 End Print

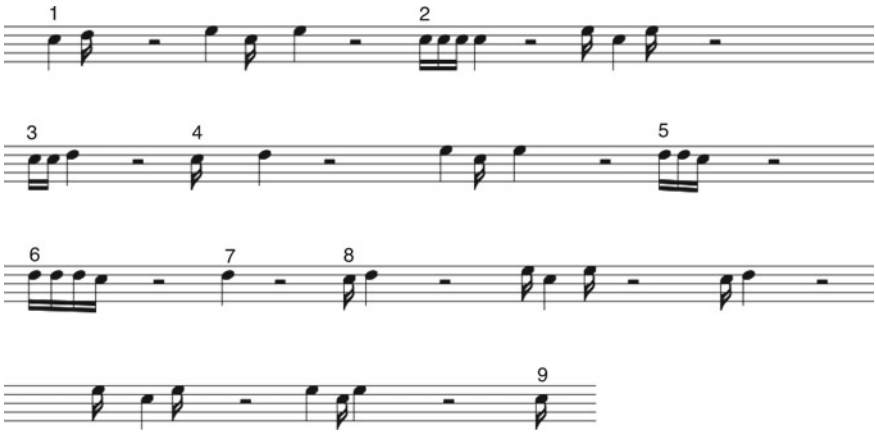

Fig. 9.12 MUSIC code to cube the number of notes whistled/hummed

played back. To understand how this MUSIC code works, it is shown in pseudocode below. Each line of pseudocode is also indicated in Fig. 9.12.

Note that MUSIC always auto-brackets from right to left. Hence, line 8 is indeed instantiated in the code shown in Fig. 9.12. Figure 9.12 also utilizes the pitch-based version of the notation discussed earlier.

9.3.6 Musico-Emotion Debugging

Once entered, a program listing of MUSIC code can be done in a number of ways. The musical notation can be displayed, either in common music notation, or in a piano roll notation (which is often simpler for non-musicians to understand). A second option is a symbolic notation such as the Symbols of '/', '.', and '-' in Column 2 of Table 9.1. Or some combination of the words in Column 3 and the symbols in Column 2 can be used. However, a more novel approach can be used which utilizes the unique nature of the MUSIC language. This involves the program being played back to the user as music.

One element of this playback is a feature of MUSIC which has already been discussed: the pitched version of the commands. If the user did not enter the

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commands with pitched format, they can still be auto-inserted and played back in the listing in pitched format—potentially helping the user understand the structure more intuitively.

In fact, a MUSIC debugger is able to take this one step further, utilizing affective and performative transformations of the music. It has been shown that when a musician performs, they will change their tempo and loudness based on the phrase structure of the piece of music they are performing. These changes are in addition to any notation marked in the score. The changes emphasize the structure of the piece (Palmer 1997). There are computer systems which can simulate this "expressive performance" behavior (Kirke and Miranda 2012), and MUSIC would utilize one of these in its debugger. As a result when MUSIC plays back a program which was input by the user, the program code speeds up and slows down in ways not input by the user but which emphasize the hierarchical structure of the code. Once again, this can be compared to the indenting of text computer code.

Figure 9.12 can be used as an example. Obviously, there is a rest between each note grouping. However, at each of the numbered points (where the numbers represent the lines of the pseudocode discussed earlier) the rest would be played back as slightly longer by the MUSIC development environment. This has the effect of dividing the program aurally into note groupings and "groupings of groupings" to the ear of the listener. So what the user will hear is when the note groupings belong to the same command, they will be compressed closer together in time—and appear psychologically as a meta-grouping, whereas the note groupings between separate commands will tend to be separated by a slightly longer pause. This is exactly the way that musical performers emphasize the structure of a normal piece of music into groupings and meta-groupings and so forth, though the musician might refer to them as motives and themes and sections.

Additionally to the use of computer expressive performance, when playing back the program code to the user, the MUSIC debugger will transform it emotionally to

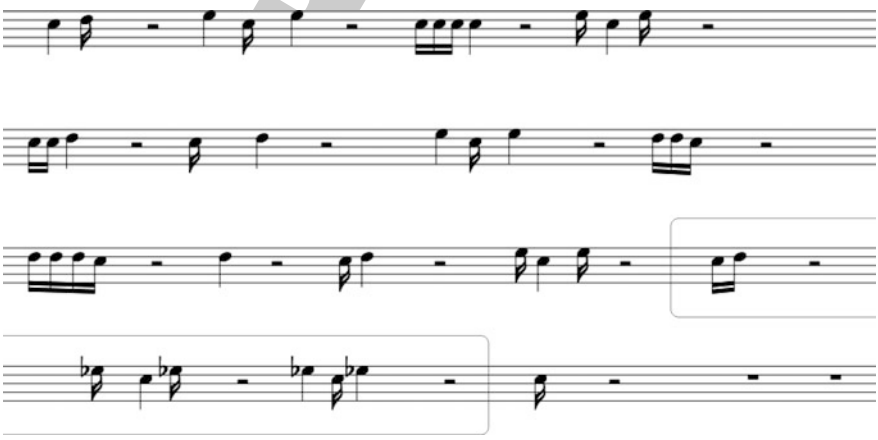

Fig. 9.13 MUSIC code from Fig. 9.10 with a syntax error

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highlight the errors in the code. For good syntax, the code will be played in a "happy" way—higher tempo and major key. For code with syntax errors, it will be played in a "sad" way—more slowly and in a minor key. Such musical features are known to express happiness and sadness to listeners (Livingstone et al. 2007). The sadness not only highlights the errors, but also slows down the playback of the code which will make it easier for the user to understand. Taking the code in Fig. 9.12 as an example again, imagine that the user had entered the program with one syntax error, as shown in Fig. 9.13.

The note grouping at the start of the highlighted area should have been a "Use Object" command from Table 9.1. However, by accident the user sang/whistled/hummed the second note too quickly and it turned into an "End Repeat" command instead. This makes no sense in the syntax and confuses the meaning of all the note groupings until the end of the boxed area. As a result when music plays back the code, it will play back the whole boxed area at two-thirds of the normal tempo. Four notes in the boxed area have been flattened in pitch (the "*b*" sign). This is to indicate how the development environment plays back the section of code effected by the error. These will turn the boxed area from a tune in the key of C major to a tune in the key of C minor. So the error-free area is played back at full tempo in a major key (a "happy" tune) and the error-affected area is played back at two-thirds tempo in a minor key (a "sad" tune). Not only does this highlight the affected area, it also provides a familiar indicator for children and those new to programming: "sad" means error.

9.4 IMUSIC

MUSIC was never implemented because of the development of the concept of IMUSIC (Interactive MUSIC). IMUSIC was inspired by a programming language proposal MIMED (Musically backed Input Movements for Expressive Development). In MIMED, the programmer uses gestures to code, and as the program code is entered, the computer performs music in real time to highlight the structure of the program. MIMED data is video data, and the language can be used as a tool for teaching programming for children, and as a form of programmable video editing. It can also be considered as a prototype for a more immersive form of programming that utilizes body rhythm and flow to create a different subjective experience of coding, almost a dance with the computer.

Rather than implementing MUSIC or MIMED, it was decided to combine ideas from the two, to create IMUSIC. It will be seen that IMUSIC involved changes to a number of elements of MUSIC. These changes were either due to discovery of more appropriate methods during practical implementation, or the adjustment of methods to fit with the new musical user interface in IMUSIC.

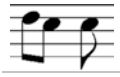
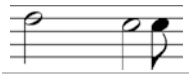
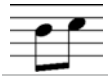
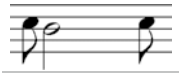
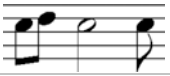
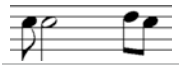
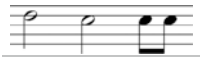
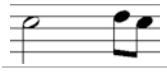
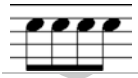
Like MUSIC, an IMUSIC code input string is a series of sounds. It can be live audio through a microphone, or an audio file or MIDI file/stream. If it is an audio input, then simple event and pitch detection algorithms (Vickers and Alty 2003) are

used to detect the commands. In IMUSIC, a dot is any sound event less than 250 ms before the next sound. A dash is a sound event between 250 ms and 4 s before the next sound event. It is best that the user avoid timings between 22 and 275 ms so as to allow for any inaccuracies in the sound event detection system.

A set of input sounds will be a grouping if the gaps between the sounds are less than 4 s and it is surrounded by silences of 4.5 s or more. Note that these time lengths can be changed by changing the Input Tempo of IMUSIC. A higher input tempo setting will reduce the lengths described above.

Table 9.2 shows some basic commands in IMUSIC. Each command is a note grouping made up of dots and/or dashes; hence, it is surrounded by a rest. Column 2 gives the Symbol notation. Figure 9.14 shows IMUSIC responding to audio input (a piano keyboard triggering a synthesizer in this case) in what is known as "verbose mode." IMUSIC is designed from the ground up to be an audio-only system. However, for debugging and design purposes having a verbose text mode is useful. Usually, the user will not be concerned with the text but only with the audio user interface (AUI).

Table 9.2 Music commands implemented

Command	Dot–dash	Name
	…	Remember
	–.	Forget
	.	Play
	..	Repeat
	-.	End
	.-.	Add
	..-.	Multiply
	.-..	Subtract
	–..	If Equal
	-..	Count
	…..	Compile

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```
IMUSIC started, please enter code...

..
[IMUSIC: <repeat>]

[IMUSIC is listening...]
...
[IMUSIC: <repeat> data]

[IMUSIC is listening...]
.
[IMUSIC: <play>]

[IMUSIC is listening...]
.--...

[IMUSIC is listening...]
-.
[IMUSIC: <end>]

[IMUSIC is listening...]
```

Fig. 9.14 Example IMUSIC input response—verbose mode

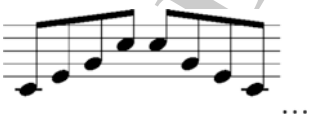

Fig. 9.15 The AUI riff

In one sense, the pitches in Table 9.2 are arbitrary as it is the rhythm that drives the input. However, the use of such pitches does provide a form of pitch structure to the program that can be useful to the user if they play the code back to themselves, if not to the compiler.

The IMUSIC AUI is based around the key of C major. The AUI has an option (switched off by default) which causes the riff transposition point to do a random walk of size one semitone, with a 33% chance of moving up one semitone and 33% of moving down. However, its notes are always transposed into the key of C major or C minor. This can be used to provide some extra musical interest in the programming. It was switched off for examples in this paper.

When the IMUSIC audio user interface (AUI) is activated, it plays the looped arpeggio—called the AUI arpeggio—shown in Fig. 9.15, the AUI riff. All other riffs are overlaid on the AUI arpeggio.

In this initial version of IMUSIC, if an invalid command is entered, it is simply ignored (though in a future version it is planned to have an error feedback system). If a valid command is entered, the AUI responds in one of following three ways:

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- Waiting Riff,
- Structural Riff, and
- Feedback Riff.

A Waiting Riff comes from commands which require parameters to be input. So once MUSIC detects a note grouping relating a command that takes a parameter (Remember or Repeat), it plays the relevant riff for that command until the user has entered a second note group indicating the parameter.

A Structural Riff comes from commands that would normally create indents in code. The If Equal and Repeat commands effect all following commands until an End command. These commands can also be nested. Such commands are usually represented in a graphical user interface by indents. In the IMUSIC AUI, an indent is represented by transposing all following Riffs up a certain interval, with a further transposition for each indent. This will be explained more below.

All other commands lead to Feedback Riffs. These riffs are simply a representation of the command which has been input. The representation is played back repeatedly until the next note grouping is detected. Feedback Riffs involve the representation first playing the octave of middle C, and then in the octave below. This allows the user to more clearly hear the command they have just entered.

For user data storage, IMUSIC currently uses a stack (Grant and Leibson 2007). The user can push melodies onto—and delete melodies from—the stack and perform operations on melodies on the stack, as well as play the top stack element. It is envisioned that later versions of IMUSIC would also be able to use variables, similar to those described in MUSIC earlier. Note that most current testing of IMUSIC has focused on entering by rhythms only, as the available real-time pitch detection algorithms have proven unreliable (Hsu et al. 2011). (This does not exclude the use of direct pure tones or MIDI instrument input; however, that is not addressed in this paper.) So when entering data in rhythm-only mode, IMUSIC generates pitches for the rhythms using an aleatoric algorithm (Miranda 2001) based on a random walk with jumps, starting at middle C, before storing them in the stack.

9.4.1 IMUSIC Commands

The rest of IMUSIC will now be explained by going through each of the commands.

9.4.1.1 Remember

After a Remember command is entered, IMUSIC plays the Remember waiting riff (Fig. 9.16—as with MUSIC all common music notation is in the treble clef). The user can then enter a note grouping which will be pushed onto the stack at execution time.

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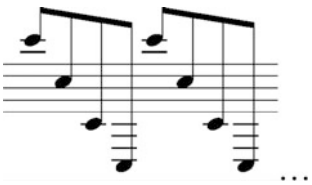

Fig. 9.16 The looped remember-riff

Once the user has entered the data to be pushed on to the stack, IMUSIC loops a feedback riff based on the rhythms of the tune to be memorized, until the next note grouping is detected.

9.4.1.2 Forget

Forget deletes the top item in the stack, i.e., the last thing remembered. After this command is entered, IMUSIC loops a feedback riff based on the Forget command tune's rhythms in Table 9.2, until the next note grouping is detected.

9.4.1.3 Play

This is the main output command, similar to "cout ≪" or "Print" in other languages. It plays the top item on the stack once using a sine oscillator with a loudness envelope reminiscent of piano. After this command is entered, IMUSIC loops a feedback riff based on the Play command tune's rhythms from Table 9.2, until the next note grouping is detected.

9.4.1.4 Repeat

This allows the user to repeat all following code (up to an "End" command) a fixed number of times. After the Repeat instruction is entered, IMUSIC plays the Repeat Waiting Riff in Fig. 9.17. The user then enters a note grouping whose note count defines the number of repeats. So, for example, the entry in Fig. 9.18 would cause all commands following it, and up to an "end" command, to be repeated three times during execution, because the second note grouping has three notes in it.

Once the note grouping containing the repeat count has been entered, the Repeat Waiting Riff will stop playing and be replaced by a loop of the Repeat Structure Riff. This riff contains a number of notes equal to the repeat count, all played on middle C. The Repeat Structure Riff will play in a loop until the user enters the matching "End" command. Figure 9.19 shows the example for Repeat 3.

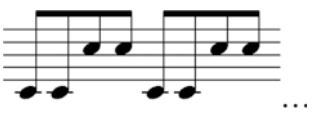

Fig. 9.17 The looped repeat-riff

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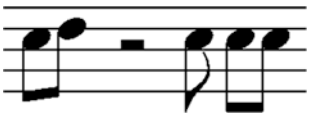

Fig. 9.18 Input for repeat 3 times

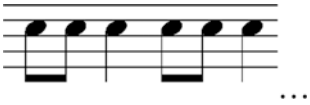

Fig. 9.19 Repeat structure riff for "repeat 3"

9.4.1.5 End

The End command is used to indicate the end of a group of commands to Repeat, and also the end of a group of commands for an "If equal" command (described later). After "end" is entered, the Repeat Structure Riff will stop playing (as will the "If equal" riff—described later). End is the only command that does not have a Riff, it merely stops a Riff.

9.4.1.6 Add

The Add command concatenates the top of the stack on to the end of the next stack item down. It places the results on the top of the stack. So if the top of the stack is music phrase *Y* in Fig. 9.20, and the next item down is music phrase *X* in Fig. 9.20, then after the Add command, the top of the stack will contain the bottom combined phrase.

After this command is entered, IMUSIC loops a feedback riff based on the Add command tune's rhythms from Table 9.2, until the next note grouping is detected.

9.4.1.7 Multiply

The Multiply command generates a tune using the top two tunes on the stack and stores the result at the top of the stack. It is related to the Operator Objects in MUSIC. If the top tune is called tune Y and the next down is called tune *X*, then their multiplication works as follows. Suppose $X = [X_i^p, X_i^t]$ and $Y = [Y_j^p, Y_j^t]$. The

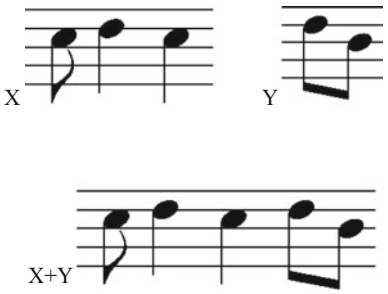

Fig. 9.20 Results of the Add command

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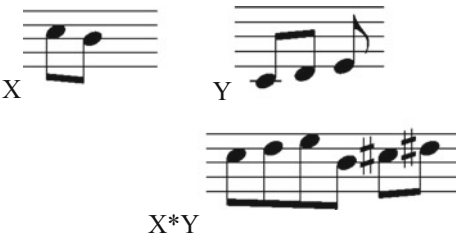

Fig. 9.21 The result of a multiply command when the *top* of the stack is *Y* and the next item *down* is *X*

resulting tune *XY* has a number of notes which is the product of the number of notes in *X* and the number of notes in *Y*. It can be thought of as tune X operating on tune *Y*, or as imposing the pitch structure of *X* onto the pitch structure of *Y*. The new tune *XY* is defined as follows:

$$XY_K^P = X_i^P + (Y_j^P - 60)$$
$$XY_K^t = XY_i^t$$

For example, suppose *Y* has 3 notes, and *X* has 2 then:

$$XY^p = [X_1^P + (Y_1^P - 60), X_1^P + (Y_2^P - 60), X_1^P + (Y_3^P - 60),$$
$$X_2^P + (Y_1^P - 60), X_2^P + (Y_2^P - 60), X_2^P + (Y_3^P - 60)]$$

and

$$XY_k^t = \left[X_1^t, X_1^t, X_2^t, X_2^t, X_3^t, X_3^t\right]$$

Figure 9.21 shows an example.

From a musical perspective, Multiply can also be used for transposition.

After this command is entered, IMUSIC loops a feedback riff based on the Multiply command tune's rhythms from Table 9.2, until the next note grouping is detected.

9.4.1.8 Subtract

Subtract acts on the top item in the stack (melody *X*) and the next item down (melody *Y*). Suppose melody *Y* has *N* notes in it, and melody *X* has *M* notes. Then, the resulting tune will be the first *M*–*N* notes of melody *X*. The actual content of melody *Y* is unimportant—it is just its length. There is no such thing as an empty melody in IMUSIC (since an empty melody cannot be represented sonically). So if tune *Y* does not have less notes than tune *X*, then tune *X* is simply reduced to a single note. Figure 9.22 shows an example.

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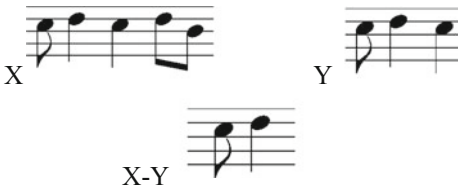

Fig. 9.22 Results of the subtract command

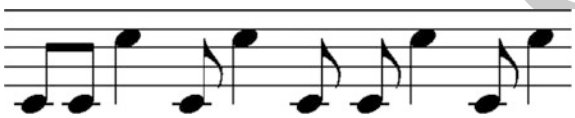

Fig. 9.23 If equal structure riff

After this command is entered, IMUSIC loops a feedback riff based on the Subtract command tune's rhythms from Table 9.2, until the next note grouping is detected.

9.4.1.9 If Equal

This allows the user to ignore all following code (up to an "End" command) unless the top two melodies in the start have the same number of notes. After the If Equal instruction is entered, IMUSIC plays the If Equal Structure Riff in Fig. 9.23.

This riff continues to play until the user enters a matching End command.

9.4.1.10 Count

The Count command counts the number of notes of the tune on the top of the stack. It then uses a text to speech system to say that number. After this command is entered, IMUSIC loops a feedback riff based on the Count command tune's rhythms from Table 9.2, until the next note grouping is detected.

9.4.1.11 Compile

The Compile command compiles the IMUSIC code entered so far into an executable stand-alone Python file. It also deletes all IMUSIC code entered so far, allowing the user to continue coding.

9.4.2 Examples

Two examples will now be given—one to explain the AUI behavior in more detail, and one to demonstrate calculations in IMUSIC. Videos and audios of both pieces of code being programmed and executed are provided (Kirke 2015).

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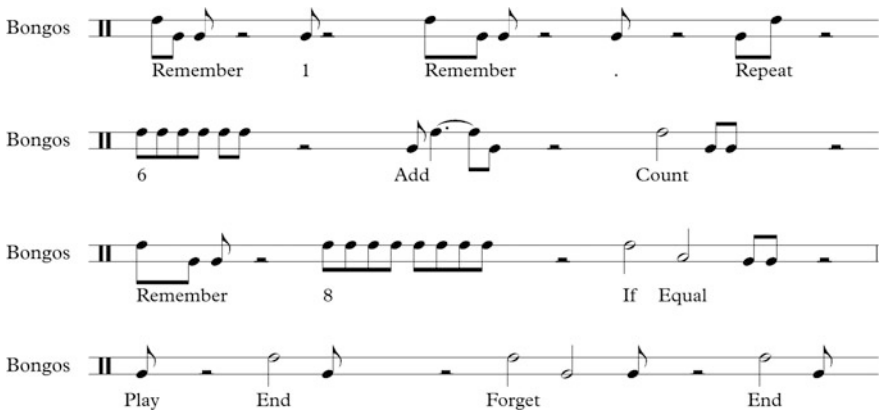

Fig. 9.24 Example code to demonstrate structure riffs in AUI

9.4.2.1 Example 1: Structure

To explain structure representation in the AUI, consider the first example in Fig. 9.24 which shows an actual IMUSIC program which was entered using bongo drums.

This program might be written in text as (with line numbers included for easy reference):

```
 1  Remember 1
 2  Remember 1
 3  Repeat 6
 4  Add
 5  Count
 6  Remember 8
 7  If Equal
 8  Play
 9  End
10  Forget
11  End
```

The output of this program is the synthesized voice saying “2”, “3”, “5”, “8”, “13”, and then “21.” However, between “8” and “13” it also plays a tune of 8 notes long. This is caused by the cumulative addition of the two tunes at the top of the

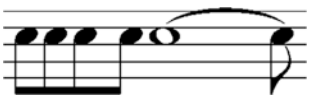

Fig. 9.25 Repeat count structure riff

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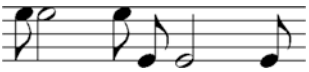

Fig. 9.26 Add command feedback riff at 1 Indent

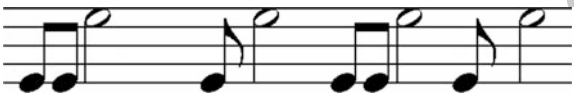

Fig. 9.27 If equal command structure riff at 1 indent

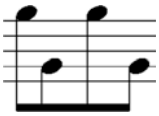

Fig. 9.28 Play command feedback riff at 2 indents

stack in line 4 of the code, and by comparing the stack top length to a tune of length 8 in line 7 of the code.

The code entry will be examined in more detail to highlight more of the IMUSIC AUI. As code entry begins, the AUI will play the AUI riff in Fig. 9.15. The Riffs for the first 2 lines have been explained already. The third line's Repeat will cause the Repeat Waiting Riff from Fig. 9.17. After the Repeat Count is entered in line 3, Fig. 9.25 is looped by the AUI to indicate that all statements now being entered will be repeated 5 times.

Because it is a Structure Riff, it continues looping until its matching End is entered. When the user enters the next command of Add, the AUI will add Fig. 9.26 as a Feedback Riff. It can be seen that it has the same rhythms as the Add command from Table 9.2.

It can also be seen that this is a major third above the Repeat Count Structure Riff in Fig. 9.25. This interval is an indication by the AUI of the single level of indent created by the earlier Repeat command. This transposition will also be applied to the Feedback Riffs of the next 3 commands (lines 5, 6, and 7). Note that each Feedback Riff stops when the next note grouping is entered. Immediately after line 7, the AUI will consist of the AUI arpeggio, the Repeat Count Riff from Fig. 9.25, and the Structure Riff in Fig. 9.27. Notice how once again it is transposed a major third up compared to Fig. 9.23.

This command embeds another "indent" into the AUI. So when the next command is entered—line 8, Play—its Feedback Riff will be a major fifth above the default position. This indicates a second level of indenting to the user, as shown in Fig. 9.28.

Then, after the End command at line 9 in entered, the Play Riff and the If Equal Structure Riff stop. Also the indentation goes back by on level. So the Forget

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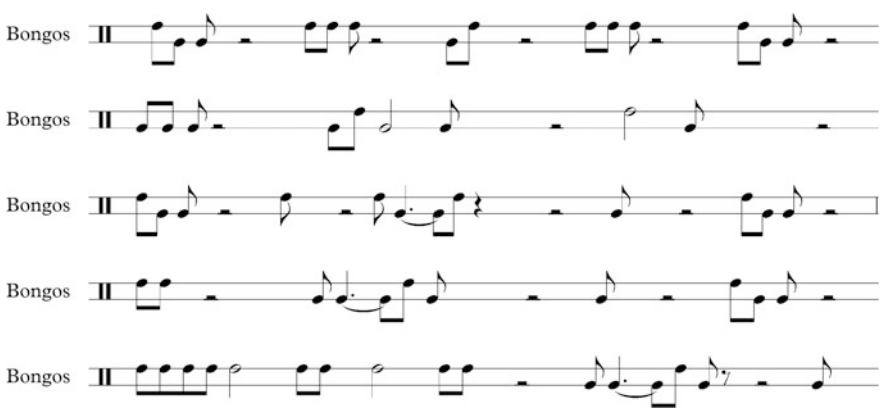

Fig. 9.29 Example code to demonstrate calculation and "compositional" code

Feedback Riff will only be a major third above its default position. Then, after the End command is entered from line 11, the Repeat Structure Riff stops, and only the AUI arpeggio remains.

9.4.2.2 Example 2: Calculation

The second example—shown in Fig. 9.29—demonstrates some simple calculations, but—like all code in IMUSIC—it can be viewed from a compositional point of view as well.

It was programmed using bongo drums and plays 3 note groupings of lengths: 82, 80, and 70—ASCII codes for R, P, and F. These are the initials of that famous scientific bongo player—Richard P. Feynman. In text terms this can be written as follows:

```
 1  Remember 3
 2  Repeat 3
 3  Remember 3
 4  Multiply
 5  End
 6  Remember 1
 7  Add
 8  Play
 9  Remember 2
10  Subtract
11  Play
12  Remember 10
13  Subtract
14  Play
```

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Note that multiple entries in this program involve counted note groupings (lines 1, 2, 3, 6, 9, and 12). The actual rhythmic content is optional. This means that as well as the output being potentially compositional, the input is as well (as note groupings are only used here for length counts). So when "precomposing" the code, the note groupings in these lines were rhythmically constructed to make the code as enjoyable as possible to enter by the first author. This leads only to a change in the rhythms for line 12. Thus, in the same way that many consider text-based programming to have an aesthetic element (2013), this clearly can be the case with IMUSIC.

9.4.3 Other Features

A moment will be taken to mention some features of IMUSIC which are planned for implementation but not yet formally implemented. One is the debugging discussed in the MUSIC formulation earlier in chapter. There are other elements which have been defined but not implemented yet which will now be discussed, to further cover topics in programming by music.

9.4.3.1 Affective Computation

Another proposed addition that was not discussed in MUSIC was affective computation. Other work has demonstrated the use of music for affective computation, defining the AND, OR, and NOT of melodies—based on their approximate affective content (Livingstone et al. 2007).

Human–computer interaction by replacement (HCI by replacement, or HBR) is an approach to unconventional virtual computing that combines computation with HCI, a complementary approach in which computational efficiency and power are more balanced with understandability to humans. Rather than ones and zeros in a circuit have the user interface object itself, e.g., if you want data to be audible, replace the computation basis by melodies. This form of HBR has been reported on previously (pulsed melodic affective processing—PMAP) (Kirke and Miranda 2014a, b). Some forms of HBR may not be implementable in hardware in the foreseeable future, but current hardware speeds could be matched by future virtual HBR machines.

The focus here will be on the forms of HBR in affective computation or in computation that has an affective interpretation. As has already been mentioned, it has been shown that affective states (emotions) play a vital role in human cognitive processing and expression (Malatesa et al. 2009). As a result, affective state processing has been incorporated into robotics and multi-agent systems (Banik et al. 2008). A further reason in human–computer interaction studies is that emotion may help machines to interact with and model humans more seamlessly and accurately (Picard 2003). So representing and simulating affective states is an active area of research.

The dimensional approach to specifying emotional state is one common approach. It utilizes an n-dimensional space made up of emotion "factors." Any

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emotion can be plotted as some combination of these factors. For example, in many emotional music systems (Kirke and Miranda 2015) two dimensions are used: valence and arousal. In that model, emotions are plotted on a graph with the first dimension being how positive or negative the emotion is (valence), and the second dimension being how intense the physical arousal of the emotion is (arousal), for example, "happy" is high valence, high arousal affective state, and "stressed" is low valence high arousal state.

A number of questionnaire studies provide qualitative evidence for the idea that music communicates emotions (Juslin and Laukka 2004). Previous research (Juslin 2005) has suggested that a main indicator of valence is musical key mode. A major key mode implies higher valence, minor key mode implies lower valence. For example, the overture of The Marriage of Figaro opera by Mozart is in a major key, whereas Beethoven's melancholic "Moonlight" Sonata movement is in a minor key. It has also been shown that tempo is a prime indicator of arousal, with high tempo indicating higher arousal, and low tempo—low arousal. For example, compare Mozart's fast overture above with Debussy's major key but low tempo opening to "Girl with the Flaxen Hair." The Debussy piano-piece opening has a relaxed feel—i.e., a low arousal despite a high valence.

In PMAP (Kirke and Miranda 2014a, b), the data stream representing affective state is a stream of pulses. The pulses are transmitted at a variable rate. This can be compared to the variable rate of pulses in biological neural networks in the brain, with such pulse rates being considered as encoding information [in fact, neuroscientists have used audio probes to listen to neural spiking for many years (Chang and Wang 2010)]. In PMAP, this pulse rate specifically encodes a representation of the arousal of an affective state. A higher pulse rate is essentially a series of events at a high tempo (hence high arousal), whereas a lower pulse rate is a series of events at a low tempo (hence low arousal).

Additionally, the PMAP pulses can have variable heights with 10 possible levels. For example, 10 different voltage levels for a low-level stream, or 10 different integer values for a stream embedded in some sort of data structure. The purpose of pulse height is to represent the valence of an affective state, as follows. Each level represents one of the musical notes C, D, Eb, E, F, G,Ab,A,Bb,B, for example, 1 mV could be C, 2 mV be D, 3 mV be Eb. We will simply use integers here to represent the notes (i.e., 1 for C, 2 for D, 3 for Eb). These note values are designed to represent a valence (positivity or negativity of emotion). This is because, in the key of C, pulse streams made up of only the notes C, D, E, F, G, A, B are the notes of the key C major and so will be heard as having a major key mode —i.e., positive valence whereas streams made up of C, D, Eb, F, G,Ab, Bb are the notes of the key C minor and so will be heard as having a minor key mode—i.e., negative valence.

For example, a PMAP stream of say [C, C, Eb, F, D, Eb, F, G, Ab, C] (i.e., [1, 1, 3, 5, 3, 4, 5, 6, 7]) would be principally negative valence because it is mainly minor key mode whereas [C, C, E,F, D, E, F, G, A, C] (i.e., [1, 1, 4, 5, 2, 4, 5, 6 ,8]) would be seen as principally positive valence. And the arousal of the pulse stream would be encoded in the rate at which the pulses were transmitted. If [1, 1, 3, 5, 3, 4, 5, 6,

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7] was transmitted at a high rate, it would be high arousal and high valence—i.e., a stream representing "happy" whereas if [1, 1, 4, 5, 2, 4, 5, 6, 8] was transmitted at a low pulse rate, then it will be low arousal and low valence—i.e., a stream representing "sad."

Note that [1, 1, 3, 5, 3, 4, 5, 6, 7] and [3, 1, 3, 5, 1, 7, 6, 4, 5] both represent high valence (i.e., are both major key melodies in C). This ambiguity has a potential extra use. If there are two modules or elements both with the same affective state, the different note groups which make up that state representation can be unique to the object generating them. This allows other objects, and human listeners, to identify where the affective data is coming from.

In terms of functionality, PMAP provides a method for the processing of artificial emotions, which is useful in affective computing—for example, combining emotional readings for input or output, making decisions based on that data, or providing an artificial agent with simulated emotions to improve their computation abilities. It also provides a method for "affectively coloring" non-emotional computation. It is the second functionality which is more directly utilized in this paper. In terms of novelty, PMAP is novel in that it is a data stream which can be listened to, as well as computed with. The affective state is represented by numbers which are analogues of musical features, rather than by a binary stream of 1 s and 0 s. Previous work on affective computation has been done with normal data-carrying techniques—e.g., emotion category index, a real number representing positivity of emotion.

This element of PMAP provides an extra utility—PMAP data can be generated directly from rhythmic data and turn directly into rhythmic data or sound. Thus, rhythms such as heart rates, key-press speeds, or time-sliced photon-arrival counts can be directly turned into PMAP data; and PMAP data can be directly turned into music with minimal transformation. This is because PMAP data *is* rhythmic and computations done with PMAP data are computations done with rhythm and pitch. Why is this important? Because PMAP is constructed so that the emotion which a PMAP data stream represents in the computation engine will be similar to the emotion that a person "listening" to PMAP-equivalent melody would be. So PMAP can be used to calculate "feelings" and the resulting data will "sound like" the feelings calculated. Though as has been mentioned, in this paper the PMAP functionality is more to emotionally color the non-emotional computations being performed.

PMAP has been applied and tested in a number of simulations. As there is no room here to go into detail, these systems and their results will be briefly described. They are (Kirke and Miranda 2014a, b; Chang and Wang 2010) as follows:

(a) A security team multi-robot system,
(b) A musical neural network to detect textual emotion, and
(c) A stock market algorithmic trading and analysis approach.

The security robot team simulation involved robots with two levels of intelligence: a higher level more advanced cognitive function and a lower level basic

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affective functionality. The lower level functionality could take over if the higher level ceased to work. A new type of logic gate was designed to use to build the lower level: musical logic gates. PMAP equivalents of AND, OR, and NOT were defined, inspired by fuzzy logic.

The PMAP versions of these are, respectively, MAND, MOR, and MNOT (pronounced "emm-not"); MAND; and MOR. So for a given stream, a PMAP segment of data can be summarized as $m_i = [k_i, t_i]$ with key value k_i and tempo value t_i. The definitions of the musical gates are (for two streams m_1 and m_2):

$$\begin{aligned} &\text{MNOT}(m) = [-k, 1-t] \\ &m_1 \text{MAND}\, m_2 = [\min(k_1, k_2),\ \min(t_1, t_2)] \\ &m_1 \text{MOR}\, m_2 = [\max(k_1, k_2),\ \max(t_1, t_2)] \end{aligned}$$

It is shown that using a circuit of such gates, PMAP could provide basic fuzzy search and destroy functionality for an affective robot team. It was also found that the state of a three robot team was human audible by tapping into parts of the PMAP processing stream.

As well as designing musical logic gates, a form of musical artificial neuron was defined. A simple two-layer PMAP neural network was implemented using the MATLAB MIDI toolbox. The network was trained by gradient descent to recognize when a piece of text was happy and when it was sad. The tune output by the network exhibited a tendency toward "sad" music features for sad text, and "happy" music features for happy text. The stock market algorithmic trading and analysis system involved defining a generative affective melody for a stock market based on its trading imbalance and trading rate. This affective melody was then used as input for a PMAP algorithmic trading system. The system was shown to make better profits than random in a simulated stock market.

In IMUSIC, the new commands for MAND, MOR, and MNOT in affective computation are shown in Table 9.3.

Table 9.3 Affective computation commands

Name	Description
MAND	MAND the top two melodies on the stack and place the result on the top of the stack
MOR	MOR the top two melodies on the stack and place the result on the top of the stack
MNOT	MNOT the top item on the stack and place the result on the top of the stack
Make Emotion <AFF_STATE>	Transform the tune at the top of stack to be <AFF_STATE> . Possible AFF_STATEs are SAD, ANGRY, RELAXED, HAPPY, POSITIVE, NEGATIVE, ENERGETIC, SLOTHFUL
If equal emotion	If the top two items of the stack have a similar emotion, do the following commands

Table 9.4 Extensions to command set

Name	Description
While	Repeat the following block of code while the top of the stack is of greater than length 1 note
While <AFF_STATE>	Repeat the following block of code while the top of the stack is in the defined affective state (HAPPY, ENERGETIC, etc.)
Swap	Swap the top two tunes on the stack around
Shuffle	Reorder the entire stack randomly

9.4.3.2 Extensions to Command Set

There are three more proposed command additions to IMUSIC which increase its programming power immediately. To increase the usefulness of the stack, a command that swaps the top two melodies on the stack improves flexibility significantly. Furthermore, a While-type command increases the decision power of IMUSIC. Finally, there is no randomness in IMUSIC, so a command that shuffles the stack would be a significant step toward improving this situation. These proposed commands are shown in Table 9.4.

9.5 Conclusions

This chapter has introduced the concept of programming using music, also known as tone-based programming (TBP). Although there has been much work on using music and sound to debug code, and also as a way of help people with sight problems to using development environments, the focus here has been on actually building programs from music.

The chapter has been structured to show the development of the field, from initial concepts, through to a conceptual language MUSIC, through to an implemented language IMUSIC. There has also been discussion of the first future planned additions to IMUSIC.

The motivations for programming using music are at least fivefold: to provide a new way for teaching script programming for children, to provide a familiar paradigm for teaching script programming for composition to non-technically literate musicians wishing to learn about computers, to provide a tool which can be used by sight-challenged adults or children to program, to generate a proof of concept for a hands-free programming language utilizing the parallels between musical and programming structure, and to demonstrate the idea of increasing flow through real-time rhythmic interaction with a computer language environment. Additional advantages that can be added include the natural way in which music can express emotion, and the use of musico-emotional debugging.

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9.6 Questions

1. Name two possible advantages of programming with music
2. Give an example of a country where a whistling language has been used.
3. Why is LogoRhythms not a musical programming language as such?
4. What is flow?
5. Name one similarity between musical structure and programming structure.
6. What has music often been described as the language of?
7. Why has emotional processing been researched in artificial intelligence and robotics?
8. What is desonification?
9. What is natural programming?
10. Give three examples of common musical structures.
11. How might musical programming help in making chat agents more believable?
12. What defines a grouping in MUSIC input?
13. How can debugging be helped in musical programming using emotions?
14. Name two commands in MUSIC
15. What are the key differences between MUSIC and IMUSIC?
16. What is the waiting riff in IMUSIC?
17. How does a stack work?
18. Name two musical logic gates.
19. Why might PMAP be useful in HCI?
20. What makes PMAP ideally suited to musical programming?

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